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Properties and Decomposition of Bark

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Abstract

The thesis is a summary based on 5 sub-reports. Bark from Norway spruce (*Picea abies* (L.) H. Karst.), Scots pine (*Pinus silvestris* L.) and birch (*Betula verrucosa* Ehrh.) were examined. Studies into the occurrence of bioelements (in the main C, N, P, K, Ca, Mg and ash) in bark have demonstrated substantial differences between fresh bark from investigated tree species as well as between fresh and partially decomposed bark. It was also shown that concentrations of bioelements varies with age and trunk width as well as with trunk level. Great compositional differences also occur between inner and outer bark.

The studies showed that the water soluble fraction in bark usually accounts for 15–25% of the bark's dry weight. The concentration of different bioelements, the chemical oxygen demand (COD) and the biochemical oxygen demand during a 7 days period (BOD_7) were analysed. When bark leachate infiltrate into soil, it was observed that leachate could release iron, result in ionic exchange processes and affect soil structure. The mineral soil was found to adsorb a considerable part of dry matter and phosphorus in the leachate. No inhibitory effects on soil respiration were noted.

The investigations demonstrated that bark decomposition is a very slow process. Inner bark is however more easily decomposed than outer bark. A classification system was compiled relating to the degree of decomposition in bark. The system was based on observable morphological characteristics. The decomposition rate in the water soluble fraction of bark was investigated. The supply of mineral nutrients was found to play an important role.

Contents

Foreword 5

Introduction 7

Composition of bark 7

Water-soluble substances in bark 9

The effects of bark leachate on soil 11

The decomposition of bark 11

List of reports included 14

Forword

A result of the increasing degree of centralization that has taken place in timber and pulpwood management during the last few decades has been the accumulation of large quantities of bark within the forestry industry. The quantities of bark at present amassed within the industry are estimated to exceed 2 million tons dry weight per year. That amount corresponds to a loose volume of approximately 15 million cubic meters. Furthermore, roughly 10 million cubic meters of bark are left lying in forests or are lost in transit from forest to industry. Since this annual accumulation occurs to such a great extent, it is not unusual to find depots in the larger concerns with over 0.2 million cubic meters. The unsuitable nature of these bark mountains from the environmental point of view is due to the leakage of foul-smelling leachate with a great oxygen demand concomitant with depot fires that are often hard to quell.

In order to come to terms with this heaping up of bark, it has proved expedient to find suitable uses for bark. One such area was the use of bark as road construction material. In this particular case, the function of bark is either to provide a type of frost resistance and thus prevent frost heaving in underlying mineral soil or to ease stress in areas with especially weak bearing capacity. In 1960 the National Road Research Institute (Statens Väginstitut) projected the first "bark road" and subsequently in 1962 the National Road Board (Väg- och Vattenbyggnadsstyrelsen) recommended experimental projects concerned with the use of bark in road constructions. As a consequence of the latter, the National Road Administration (Statens Vägverk) published instructions of technical nature related to the use of bark in road constructions.

The biological conditions behind this use of bark soon became an object of study for Professor Nils Nykvist who carried out orientation investigations. However, several questions relating to the characteristics of bark and its decomposition remained to be answered, as a result of which Nykvist initiated this investigations of a more comprehensive nature in 1972.

However, outside factors made the utilization of bark in road construction a much less interesting proposition, this being partly due to the 1974 petroleum crisis and partly to the discovery that water-soluble organic substances which were leached out of bark under certain conditions severely polluted recipients. Thus all in all, the use of bark for road construction purposes is of a small extent. The upsurge in interest in firing with bark led, for example, to the sawmilling industry utilizing 50% of its total bark volume for firing purposes. It should be pointed out that the firing referred to was not merely combustion of a destructive nature but a serious attempt to exploit for heating purposes the energy contained in bark. A very large proportion of remaining bark volumes are still left lying in heaps while smaller quantities are now being used to produce soil improvement material. When bark is stored in large depots, used in other

ways or when timber and pulpwood are managed as at present by the forestry industry, water-soluble compounds occasion serious problems. The need for an increase in knowledge concerning these compounds has concequently been great. In order to facilitate the use of bark, it was also deemed necessary to produce a method to classify the degree of decomposition in bark.

The present thesis is a summary of 5 reports which will be reviewed in order of publication (page 14). More precise information on specific results, methods and references may be obtained from the above-mentioned reports.

Report I comprises an orientation study produced in connection with investigations carried out into the use of bark for road construction purposes. The remaining four reports were produced in the main simultaneously. The studies comprised investigations into the concentrations of different bioelements in fresh bark (Report IV) and a comparative study of the structure and composition of bark in different stages of decomposition, assessed on the basis of external morphological characteristics (Report II). The latter gave rise to a system of classification, whereby the degree of decomposition in bark could be gauged. Reports III and V are studies of water-soluble substances and their properties in bark.

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Introduction

The inner bark of tree trunks is built up of cambium and secondary phloem. In younger trees there also exists cortex tissue. These different types of tissue are composed of living cells. At a certain distance from the cambium, there develops a phellogen layer (bark cambium) in the inner bark which produces phelloderm cells inwards towards the centre of the trunk and phellem cells outwards towards the periphery (cork). The phellogen and the tissues it produces are known collectively as periderm. The phellem cells in the periderm die shortly after formation and after a time, the phellogen layer ceases to function, the functional interval varying from species to species. In pine trees, this layer functions for only a short space of time while in birch it is comparatively long-lived. New phellogen and periderm layers are produced continuously inside the older ones. The inner bark cells are thus isolated from the rest of the tree whereby they die. The term outer bark refers to the periderm and such inner bark as is enclosed between periderm layers. The outer bark comprises exclusively dead tissue.

Total bark is a term used to embrace both the outer and the inner bark and consequently, all the types of tissue that are located outside the xylem. The division between inner and outer bark is, to some extent, based on physiological aspects. The inner bark is made up of living cells, many of which participate actively in the transport of photosynthesized material within the trunk while the dead outer bark has a protective function.

Bark is composed almost exclusively of organic components to which a small number of mineral compounds are bound. Spruce and pine bark is generally considered to be made up of 50–60% carbohydrates, 30–40% lignin, 2–3% suberin plus water-soluble compounds and lipophile extractive substances. The carbohydrate fraction is in the main composed of cellulose. Bark lignin differs from wood lignin chemically speaking and comprises phenolic derivatives. The water-soluble fraction is made up of 20–30% carbohydrates, 50–70% tannin, 10–20% phenolic derivatives and phenolglucosides plus different acids and alcohols.

Composition of bark

Studies into the occurrence of different bioelements in bark (report IV) have demonstrated substantial differences between the bark from spruce (*Picea abies* (L.) H. Karst.), pine (*Pinus silvestris* L.) and birch (*Betula verrucosa* Ehrh.). It has also been shown that the composition of the bioelements varies with age and trunk size as well as with height level in the trunk. Great compositional differences also occur between different types of tissue, e.g. inner and outer bark.

Total bark, i.e. inner bark plus outer bark, can generally be characterized by the fact that calcium accounts for its quantitatively dominant inorganic portion with contents of 0.3–0.8% (Table 1). This corresponds to an approximate calcium oxide content in ash of 50–60%. The ratio between contents of carbon, nitrogen and phosphorus was in the region of 150:1:0.1. The relation between calcium and magnesium is approximately 10–20:1. Manganese is the most dominant trace element with a percentage value of 0.09%.

Table 1. Concentration of bioelements in trunk bark from entire trees (report IV).

Tree species	N %	P %	K %	Ca %	Mg %
Spruce	0.44	0.057	0.24	0.81	0.085
Pine	0.28	0.034	0.11	0.34	0.034
Birch	0.38	0.031	0.14	0.80	0.038

It was demonstrated that inner bark has higher concentrations of the majority of the inorganic elements than outer bark. The differences between the two tissue types are especially noteworthy with regard to potassium, magnesium and phosphorus. In addition, the differences between inner and outer bark are appreciably larger in pine than in spruce, i.e. the inner bark of pine is richer in nutrients than that of spruce whereas the outer bark of spruce is richer in nutrients than that of pine. The concentrations of potassium, magnesium and phosphorus in the outer bark of pine amounts to only 5% of those in the inner bark. The corresponding figure for spruce is 20%. No such differences between the two tissue types were registered in the case of nitrogen, where the concentrations in the outer bark are 35 and 70% of those in the inner bark of pine and spruce respectively. The reason why the inner bark of spruce contains lower concentrations of inorganic elements is a result of the slower outer bark formation, during which a non-functional phloem accumulates. In pine, on the other hand, there occurs a more extensive outer bark proliferation at the expense of the inner bark. This entails a smaller amount of inner bark in pine and a subsequent decrease in the accumulation of non-functional phloem.

The studies have shown that the concentrations of different bioelements in total bark are higher in spruce than in pine while birch occupies a position in between. The only exceptions to this is carbon, which is found in higher concentrations in pine bark, and nitrogen, the highest concentration being registered in birch and then spruce. The differences between bark from different species are especially great as regards potassium, magnesium and phosphorus. In middle-aged and old trees, the potassium content in total bark is for instance 0.2% in the case of spruce and 0.1% in that of pine. The differences in the bioelement contents of total bark are to a great extent due to differences in anatomical structure in different species. Spruce bark consists to a great degree of inner bark characterized by a high nutrient content while that of pine in the main comprises an outer bark extremely poor in nutrients (rhytidome). An important exception is the smooth and thin bark found in the upper levels of pine trunks. The smooth bark of pine is largely made up of inner bark and its bioelement contents are of roughly the same order as those in spruce bark. The average concentrations as concerns the total amount of trunk bark are usually obtained by assessing the contents in bark from the trunk's basal sections since the greatest amount of bark is to be found there. In this way, concentrations in the total bark amount will be less for pine than for spruce.

As age and trunk width increase, the concentrations of the majority of the inorganic bioelements in total bark was found to decrease. In the case of pine, this is due to the fact that the outer bark volume increases while in the case of spruce it depends on a decrease in bioelement concentrations in both the inner and outer bark. Thus, there exists a fundamental difference between pine and spruce bark in this particular respect. In pine, the inner bark bioelement concentrations are more or less independent of age and trunk width whereas the inner bark of spruce contains increasingly smaller concentrations as time goes by and the trunk becomes thicker. In addition, the total bark concentrations of the majority of bioelements increase with higher trunk level. In the case of spruce, this is due to the fact that the inner bark concentrations vary, but in the case of pine it is caused by variations in the ratio between inner and outer bark. An exception to the above is calcium, the concentrations of which decrease with trunk level and increase with age and trunk width. Carbon concentrations also vary in a similar manner but the variations are not as great.

The content of inorganic bioelements is also considered to vary with the general properties of the site, e.g. the chemical composition of soil. It is also probable that bioelement concentrations vary on a seasonal basis, especially in the case of inner bark, but also to some extent in that of outer bark.

The investigations also point to the fact that the weight percentage of inner bark is greater in spruce than in pine (report IV). In middle-aged and old trees (referring to a rotation period of about 100 years), the inner bark portion of the lower trunk sections accounts for 50–60% of the total bark weight in spruce and approximately 15% in pine. In younger trees, however, the proportion of inner bark is greater. As concerns pine the inner bark portion increases significantly higher up the trunk.

Water-soluble substances in bark

The studies showed that the total water-soluble material usually accounts for 15–25% of the bark's dry weight (report V). The differences between inner and outer bark are great inasmuch as inner bark comprises approximately 20–25% water-soluble material while outer bark has only about 2–3%. Thus, the differences between species, age groups and trunk levels will, in the main, be dependent on the degree to which the bark is made up of either inner or outer bark.

When water-extracting fresh wet bark, only a small fraction of the water-soluble substances is leached out. If the bark is dried, subsequent water extraction was shown to release approximately 10 times more substance (report I). This is due to the fact that drying destroys the cells' semipermeable membranes which enclose the cell contents. Freezing and subsequent thawing, as well as decomposition, also destroy the semipermeable membranes and thus provide a better prerequisite for leaching.

The dry matter of bark leachate is composed almost exclusively of organic substances with an average carbon content of 50%. The ash content is approximately the same in both the dry matter of the leachate and in the bark. The high percentage of water-soluble organic matter in the bark means that the oxygen demand of the leachate will be great when biological and chemical oxidation take place.

The analytical methods usually employed to chart the oxygen demand of pollutants in water are, on the one hand, the chemical oxygen demand (COD) and, on the other,

the biochemical demand during a period of 7 days (BOD_7). The chemical oxygen demand in bark leachate amounts to 1.26 g oxygen per g dry matter, corresponding to 200–300 g per kg bark dry weight (report V). When analyzing the chemical oxygen demand the organic compounds are oxidized to 90–95%. The total oxygen requirement expected for the complete oxidation of the dry matter will thus approach the chemical oxygen demand very closely but remains somewhat higher.

The biochemical oxygen demand during a period of 7 days is due to microbial activity and thus also to the degree of facility with which organic compounds can be decomposed. The analysis is carried out under standardized conditions with a sufficiently large supply of oxygen and nutrients. The studies showed that BOD_7 usually accounts for approximately 30% of COD, which means that a comparatively large portion of the decomposition of dry matter takes place in a short space of time. This is why a large oxygen demand can rapidly arise in bark leachate or in recipients polluted by leachate.

The leachate obtained from the water extraction of bark contains inorganic bioelements as well as organic compounds. The mutual relationship of these bioelements was found to differ in a characteristic manner from that observed in bark. This was due to the varying solubility of the bioelements. Potassium and phosphorus are easily leachable, their water-soluble portions accounting for 90 and 40% of the bark's total potassium and phosphorus content respectively. Magnesium can also be leached out fairly easily while calcium and nitrogen are harder to leach. Bark leachate is thus characterized by higher carbon/nitrogen ratios and lower calcium/potassium ratios than is the case with bark. The pH in fresh leachate is approximately 5. Under anaerobic conditions, fermentation may lower the pH significantly, at the same time as foul-smelling compounds are produced, e.g. butyric acid. The specific electrical conductance is dependent on the concentrations of the different substances dissolved in the leachate. The studies showed that conductivity is in the region of 44 μ mho when the dry matter concentration is 1 g per liter.

The concentration of organic matter in bark leachate is directly related to the amount of water-soluble matter in bark, dilution factors, contact time and the efficiency of the leaching process. Under field conditions, leaching takes place much more slowly than in the laboratory. In an experiment concerned with storage of spruce and pine pulpwood under water sprinkling, it was ascertained that the amount of matter extracted each day in the drainage water from the pulpwood stacks corresponded to approximately 0.1% of the bark's dry weight (report III). This figure should be compared with the bark's total content of water-soluble substances, viz. 15–25%. The sprinkling experiment also showed that the concentration of pollutes in the drainage water is at its highest during the initial phase of treatment, probably as a result of the fact that bark retains much of the water supplied initially. Thus the volume of drainage water decreases and the concentration of pollutants increases. As sprinkling progresses, the concentrations of dissolved matter decrease successively. This is natural since the bark gradually becomes emptied of its water-soluble matter as a direct result of both leaching and decomposition.

Although pulpwood sprinkling only releases a small portion of the water-soluble fraction in bark, the total amount of released matter during an entire sprinkling season will be appreciably greater, due, as a rule, to the great quantities of bark. Leach water obtained from sprinkling 10,000 cubic meters of pulpwood contained

approximately 1.5 kg of phosphorus per day and 170 kg of dissolved matter, the latter corresponding to a chemical and biochemical oxygen demand of 210 kg and 40 kg oxygen respectively (report III). This degree of pollution is of nearly the same order as that in sewage water from a village with a population of 700 people.

The effects of bark leachate on soil

When bark leachate comes into contact with mineral soil, the properties may be affected considerably. It was observed (report V) that leachate can release iron from mineral soil, the iron content of leachate thus rising rapidly from 0.5 to 75 ppm. In finely grained soil, it was noted that the potassium and hydrogen in leachate can be exchanged for the mineral soil's calcium. This exchange is the direct result of a divergent ion-balance between the potassium and calcium in the leachate and that in the soil solution or among the ions adsorbed to the soil particles. Mineral soil rich in iron and aluminium oxides and hydroxides, i.e. the illuvial or B horizon, adsorbs a considerable amount of the organic matter and phosphorus compounds in bark leachate. When leachate was treated with B-horizon soil for a period of 24 hours, the concentration of dissolved matter fell by 40% while the concentration of dissolved phosphorus fell by over 90%. Sand filtration, possibly hand in hand with some form of oxygenation, could prove to be a suitable method of depolluting bark leachate in the forestry industry. The depollution process might be made even more efficient if sand from the B horizon were used.

When leachate infiltrates into soil, the structure deteriorates. This is caused by an exchange of divalent ions for monovalent ones which are adsorptively bound to soil particles, e.g. Ca^{2+} for K^{+} , and by the introduction of organic dispersant media into the soil. This may, under unfavourable conditions in finely grained soils, give rise to the formation of quick clay, i.e. clay types characterized by structures which collapse easily, even under a low degree of tension, resulting in landslides.

Bark leachate was also able to block the soil's pore system by breaking down the aggregate structure. The soluble matter in leachate partly precipitates in insoluble form, thus forming a type of sediment in the soil's pores (report III). The blocking of pores is an especially serious matter in soils with a finely grained structure, where lowered infiltration and aeration capacity usually entail vegetation damage as an inevitable consequence.

No inhibitory effects on soil respiration were noted after the soil had been infiltrated by small amounts of leachate (report V). On the other hand leachate was demonstrated to favour microbial activity in soil by means of its relatively easily decomposable organic matter, a so-called priming effect. When larger quantities of leachate are introduced, however, decomposition may be inhibited by the immobilization of nitrogen and phosphorus and the transition to anaerobic conditions.

The decomposition of bark

Bark decomposition is a very slow process. This is due to the fact that a great deal of bark is composed of organic substances that are difficult to break down, e.g. lignin, phlobaphene and suberin, as well as an excessively low inorganic nutrient content.

It is considered that carbon, nitrogen and phosphorus concentrations ought to be in the ratio of 50:1:0.5–0.1, when organic matter is microbially decomposed. As has been stated above, the studies have shown that the nitrogen and phosphorus concentrations in bark are appreciably lower (150:1:0.1), thus contributing to an inhibition of decomposition.

The investigations revealed, however, that inner bark is much more easily decomposed than outer bark (report II). The reason for this is that inner bark is composed of greater quantities of cellulose and less lignin and that it has a somewhat higher content of inorganic nutrients. Moreover, inner bark was found to be composed to 20–25% of water-soluble organic substances, e.g. low-molecular carbohydrates. The organic water-soluble compounds have proved to be of especially great importance as regards the decomposability of inner bark, partly because they are in themselves easily decomposed and partly because they serve as "starters" in the decomposition process and thus contribute to a more rapid decomposition of the bark's structural components (priming effect).

The rate of decomposition is dependent on the type of bark (inner or outer), the oxygen and water supply and climatic conditions such as temperature. Mixing of a bark deposit also improves the decomposition rate. Likewise, the size of the bark fragments and the possibility of a nutrient supply also play an important part. The rate of decomposition was defined by a series of experiments. After spruce bark had been stored under aerobic conditions at a temperature of 20°C, there resulted a weight decrease of approximately 25% of the dry weight after a period of 120 days (report I). During the first 25 days, this loss in weight corresponded to an equally large reduction in the amount of water-soluble matter, i.e. only the water-soluble substances were broken down during this initial phase. It was only subsequently that the structural components in bark were subjected to decomposition. If the bark was treated beforehand by means of water extraction, the resulting decrease in weight was of the order of only 5% after the first 120 days.

A decomposition experiment carried out in the field (litter-bag method) showed that the weight loss in the case of inner bark from pine amounted to 26% after approximately 150 days and to 32% after roughly 450 days (report II). The corresponding weight loss for outer bark during the same period never exceeded 5%. A large percentage of the weight lost by inner bark was due to the disappearance of water-soluble substances which may either have leached out or decomposed.

A description of the decomposition of bark begins with a precipitation of leaf-browning substances in the parenchymatous cells, thus giving the inner bark a dark colour. Simultaneously, the most easily decomposed substances are broken down, i.e. the water-soluble, low-molecular carbohydrates. The decomposition of the inner bark's structural components, which are composed of sieve and parenchymatous cells rich in cellulose, does not take place until after the water-soluble fraction has been used by up to a certain extent. The outer bark is much more resistant and thus decomposition takes place much more slowly. As decomposition progresses and matter losses increase, there occurs a gradual deterioration in the firmness of the bark, which loses its consistency and, under dry conditions, becomes brittle. During decomposition, intermediate products are formed which become condensed and polymerized to high-molecular and relatively stable humus substances.

Using the decomposition and observable changes in bark as a guide-line, a classification system was compiled relating to the degree of decomposition in spruce

and pine bark (table 2). The purpose of this classification system is to facilitate the choice of bark types for use in different areas. Bark that had attained a more advanced state of decomposition was also observed to be characterized by higher concentrations of nitrogen, calcium and ash, as well as by a lower carbon/nitrogen ratio, a higher cation exchange capacity, degree of base saturation and pH (report II).

Table 2. Classification of the degree of decomposition in bark (report II).

Class 1.	FRESH BARK Hard or tough consistency. Inner bark light and unaffected.
Class 2.	SLIGHTLY DECOMPOSED BARK Inner bark distinctly darkened but still hard or tough. Outer bark apparently unaffected.
Class 3.	PARTIALLY DECOMPOSED BARK Only insignificant remains of inner bark, which is extremely loose and more or less amorphous in structure. Outer bark in part slightly brittle or spongy.
Class 4.	HEAVILY DECOMPOSED BARK No inner bark remains. Greater part of bark mass lacks structure.
Class 5.	BARK HUMUS Less than 10% of bark fragments remain. The structure resembles that in highly humified peat.

Decomposition processes in the water-soluble fraction of bark usually attract a great deal of interest since this fraction can pollute recipients. These studies showed that analyses of the biochemical oxygen demand during a 7 day period overestimate the oxygen demand necessary under natural conditions in the field (report V). The BOD₇ analyses revealed that, as a rule, approximately 30% of the dry matter in bark leachate can be oxidized in 7 days. In the field, however, decomposition probably does not exceed 10% of the dry weight. This corresponds to a maximum oxygen demand of 130 g oxygen per kg leached dry matter.

The supply of inorganic nutrients, especially nitrogen and phosphorus, was found to be of paramount importance to the rate of decomposition of the water-soluble substances. The nitrogen concentration in water-soluble matter has, for example, been demonstrated to be lower than that in bark as a whole.

The investigations have also shown that the biological decomposition of bark is a time-consuming process which begins at a rapid rate but decreases in speed as the easily decomposed matter is utilized. After 30 days under natural conditions, probably less than 20% of the water-soluble fraction is broken down. In the presence of an adequate supply of inorganic nutrients, decomposition may be appreciably more comprehensive, in fact up to 3 times more so.

From the environmental point of view, however, decomposition is most interesting during its initial phase since the oxygen demand is then at its highest. In conclusion, the first stage in the decomposition of the leached dry matter, places testing demands on the recipient's capacity to supply the oxygen necessary.